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PLASMA PROCESSING DEVICE

Akihira Morishita et al.

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PLASMA PROCESSING DEVICE

[Purazuma shouri souchi]

Inventor:	Akihira Morishita et al.
Applicant:	Toshiba Corporation

[There are no amendments to this patent.]

Claims /1*

1. A plasma processing device characterized in that it is provided with: a plasma processing chamber equipped with a cathode to which high-frequency power is applied, and on which a specimen is placed, and with an anode situated opposing the aforementioned cathode; a means for introducing a gas to be excited into this processing chamber; a means for exhausting the aforementioned processing chamber; and a magnetic field generating means that is arranged external to the aforementioned processing chamber and facing the aforementioned cathode; said [means] is comprised of a magnetic core and multiple coils that are wound around said magnetic core in a direction perpendicular to the aforementioned cathode, and to which alternating current

* [Numbers in the margin indicate pagination of the original foreign language text.]

of different phases is applied; and that generates a magnetic field that moves continuously in a prescribed direction above the aforementioned cathode.

2. The plasma processing device according to Claim 1, characterized in that the aforementioned gas to be excited is a reactive gas, and the specimen arranged on the aforementioned cathode is thereby etched.

3. The plasma processing device according to Claim 1, characterized in that a film is formed by means of vapor phase growth on the surface of the specimen arranged on the aforementioned cathode.

4. The plasma processing device according to Claim 1, characterized in that the specimen arranged on the aforementioned cathode is a target which is a raw material used to form a film, and by sputtering this target a film is formed on a material arranged on the aforementioned cathode.

5. The plasma processing device according to Claim 1, characterized in that the aforementioned magnetic core is [approximately] tooth-shaped in cross section, [its] multiple grooves are arranged such that they oppose the aforementioned cathode, and the aforementioned coils are wound in a ring around the aforementioned magnetic core such that one end [of a coil] is packed into the aforementioned grooves, and the other end is positioned on the opposite side of said grooves.

6. The plasma processing device according to Claim 1, characterized in that the surface of the aforementioned magnetic core is larger than that of the aforementioned specimen.

7. The plasma processing device according to Claim 1, characterized in that the aforementioned multiple coils are comprised of 3n phase (n is a positive integer) coils, and a 3n-phase alternating current runs through these coils.

8. The plasma processing device according to Claim 1, characterized in that the space wherein the aforementioned magnetic field generating means is arranged is at a pressure of 10^{-4} (torr), or is at atmospheric pressure. /2

9. The plasma processing device recorded in Claim 1, characterized in that the aforementioned cathode is provided with a magnetic material outside of the area wherein the aforementioned specimen is arranged.

<u>Detailed explanation of the invention</u>

Industrial application field

The present invention pertains to a plasma processing device used in the manufacture of a semiconductor device; in particular, it pertains to a plasma processing device that performs high-speed dry etching or film formation using magnetron discharge.

Background of the invention and problems therein

In recent years semiconductor integrated circuits have become smaller and smaller, and recently extremely small devices with a minimum size of 1-2 (μm) have been developed experimentally. For this type of extremely small processing, typically the specimen is etched by means of a physical chemical reaction using a method known as reactive ion etching (RIE: Reactive Ion Etching), wherein a reactive gas such as CF_4 or CCl_2 is introduced into a container that has been vacuum exhausted and that has parallel planar electrodes, a glow discharge is generated by applying high-frequency power to the electrode on which the specimen rests (the cathode), and positive ions in the plasma - accelerated by means of the negative, direct current self-bias (cathode voltage decrease) generated at this cathode – irradiate the specimen at a perpendicular [angle]. However, this RIE by means of parallel planar electrodes uses a glow discharge with a comparatively low gas decomposition effect; therefore, for example the highest etching speed for SiO_2 using $CF_4 + H_2$ gas does not exceed 300-400 Å/min; etching of SiO_2 with contact holes or the like with a film thickness of 1 μm requires several tens of minutes or more, which is a severe defect with respect to mass production. Thus, a increase in the etching speed is desired.

In this regard the present inventors invented a dry etching device (Japanese Kokai Patent Application No. Sho 57 [1982]-98678) wherein a magnetic field generating means comprised of a permanent magnet is provided under a cathode to which high-frequency power is applied, enabling high-speed etching by means of magnetron discharge. As shown in Figure 8, the principle of this invention is that: by means of a magnetic field 3, generated in the magnetic pole intervals 2 that form the open loops of permanent magnet 1, and an electric field 4 that directly crosses this magnetic field 3, element 5 is made to operate as a cycloid so that the frequency with which it collides with the introduced reaction gas is greatly increased, generating a large amount of reactive ions. Note that in the figure, 6 indicates the specimen to be etched. As a result, a large amount of ions impact specimen 6 vertically, producing high-speed anisotropic etching.

However, a device of this type has the following problems; that is, when the aforementioned magnetic pole intervals 2 are at rest, only the high-density magnetron discharge region 7 generated in the form of tracks [transliteration] is etched, and in order to etch the entire specimen 6 it is necessary to scan magnetic pole intervals 2 [across a distance] greater than the diameter of specimen 6. Figure 9 is a characteristic diagram showing the result of measuring etch rate as a function of the distance from the edge of the specimen when SiO_2 it etched with CF_4 gas. As shown in Figure 10, magnetic pole intervals 2 came to rest at a distance of 30 mm from the edge of specimen 6. From Figure 9, it can be seen that near the edge of the specimen approximately 1000-2000 (Å) is etched in 10 seconds of etching, while the etch rate is slower further in from the edge of the specimen. Even if the aforementioned scanning time is, for

example, as fast as 0.05 sec, with approximately 80 scans the magnetic pole intervals 2 stop at either edge of specimen 6 for 2 sec; accordingly, for this number of scans the depth at the edge of the etched specimen would be close to 500 (Å) with the situation shown in Figure 10. Such a rapid etching of the perimeter region results in a decrease in uniform etching of the entire specimen. As a means of preventing this, the width of the scan of magnetic pole intervals 2 can be increased, but this leads to an increase in the size of the device and a decrease in the etch rate, which makes it difficult to handle future increases in diameter (greater than 6 inches).

Moreover, the aforementioned problem is not limited to etching; the same can be said for film formation by means of plasma CVD and sputtering deposition as well. In the case of sputtering deposition, for example, when parallel planar electrodes are used to form a film, with a target arranged as a specimen on the cathode and a wafer on which a film is to be formed /3 arranged on the anode, the target on the cathode is not etched uniformly, and the film formed on the specimen [sic; 'wafer'] is not uniform, [so] a uniform film cannot be formed; in addition, the service life of the target is reduced.

Objective of the invention

The purpose of the present invention is to offer a plasma processing device that can etch a specimen at high speed or that can form a film of uniform thickness on a specimen without increasing the size of the device, and that can handle sufficiently an increase in the diameter of the specimen.

Outline of the invention

The essence of the present invention is the use of a magnetic field generating means that electrically generates a magnetic field that can be moved continuously in a prescribed direction, rather than using the aforementioned permanent magnet having magnetic pole intervals.

In other words, the present invention is provided with: a plasma processing chamber equipped with a cathode to which high-frequency power is applied, and on which a specimen is placed, and with an anode situated opposing the aforementioned cathode; a means for introducing a gas to be excited into this processing chamber; a means for exhausting the aforementioned processing chamber; and a magnetic field generating apparatus [sic] that is comprised of a magnetic core and multiple coils that are wound around said magnetic core in a direction perpendicular to the aforementioned cathode, and to which alternating current of different phases is applied; that is arranged external to the aforementioned processing chamber and facing the aforementioned cathode; and that applies a magnetic field toward the surface of said cathode and continuously moves this magnetic field in one direction; and by means of the aforementioned magnetic field generating apparatus a progressing magnetic field is generated at

the surface of the cathode, and theoretically a high-density plasma region is scanned uniformly in one direction above a specimen.

Effect of the invention

By means of the present invention, a high-density plasma region is continuously scanned in one direction by means of the magnetic field generating means comprised of a magnetic core and multiple magnetic coils, so when a specimen [sic; 'target'] to be etched is arranged as a specimen on the cathode, the entire specimen can be etched at a high speed. Moreover, when the magnetic pole intervals are scanned back and forth, problems wherein the etch rate near the edge of the specimen becomes particularly fast or the like do not occur, and the entire specimen can be etched uniformly. Furthermore, when a specimen on which a film is to be formed is arranged on the cathode, the uniformity of that film can be improved. Moreover, when a target is arranged on the cathode as the specimen and a material on which a film is to be formed is arranged on the anode, the target is etched uniformly at a high speed, so the film can be quickly and uniformly formed on the specimen [sic; 'material']. In addition, the aforementioned scanning of the high-density plasma can be performed electrically – in other words, the magnetic field can be moved continuously in one direction while the magnetic field generation means is stationary - so the device can be made more compact. Moreover, for the aforementioned reason structurally moveable parts become unnecessary, and an improvement in reliability can be achieved. Accordingly, its usefulness with respect to the field of semiconductor manufacturing technology is certain, and it can handle an increase in the diameter of the specimen as well.

Application example of the invention

Figure 1 is a diagram illustrating the overall structure of a dry etching device pertaining to a first application example of the present invention. In the figure, 11 is a grounded container, and this container 11 is separated into a etching chamber (plasma processing chamber) 13 and a magnetic field generation apparatus enclosure 14 by means of a cathode 12. High-frequency power is applied to cathode 12 through a matching circuit 15 by means of a high-frequency power source 16. In addition, cathode 12 is cooled by a cooling water conduit 17, and this cooling water conduit 17 is used as the lead in the application of the aforementioned power. Etching chamber 13 is provided with a gas inlet 13a, for the introduction of a reactive gas such as CF_4, and with a gas exhaust port 13b for exhausting of the aforementioned gas. In addition, a specimen to be etched 18 is arranged on cathode 12 within etching chamber 13. Moreover, an anode is formed in the upper wall of chamber 13, opposing cathode 12.

In addition, within the aforementioned magnetic field generation apparatus enclosure 14, a magnetic field generation apparatus 40 comprised of a magnetic core 20 and coils 30

comprised of several tens or more of bundled, narrow, conductive wires are arranged facing the lower surface of cathode 12. As shown in Figure 2, magnetic core 20 is [comprised of] layers of thin plates of a magnetic material; on its upper surface multiple grooves 21 are formed at fixed intervals, with its cross section in a roughly tooth shape. The length of grooves 21 is greater than the diameter of specimen 18, just as the length of magnetic core 20, which is perpendicular to /4
grooves 21, is greater than that of specimen 18. A cooling plate 22 containing cooling water is attached to magnetic core 20, and by means of cooling water conduits 23 connected to cooling plate 22 the cooling water is circulated within cooling plate 22 to cool magnetic core 20. Moreover, magnetic core 20 is configured such that it can be separated into a roughly tooth shape core 20a and a back core 20b, so that after the aforementioned coils 30 are manufactured, one end of [each] coil 30 can be packed into a groove 21 of magnetic core 20. In addition, the aforementioned coils are comprised of first through third coils 31a, 31b and 31c, so as shown in Figure 3(b) they are wound cyclically in a ring in grooves 21 of magnetic core 20. In other words, coil 31a is wound around magnetic core 20 such that one end is packed into a groove 21 and the other end is positioned on the opposite side of said groove 21, and it is series connected to every third groove 21. It is the same with the other coils 31b and 31[c]. In addition, 3-phase alternating current of different phases is run through coils 31a, 31b and 31c.

Here, as shown in Figure 3 (a), when 3-phase alternating current having 120-degrees different phases is run through the aforementioned coils 31a, 31b and 31c, a magnetic flux density B is generated above magnetic field generating apparatus 40 - that is, above the aforementioned cathode 12 – [said flux] given by the following formula:

$$B = B_0 \cos(\omega t - \pi x / \tau) \cdots\cdots ①$$

where ω = 2π[;] f: current angular frequency (rad /s)[;] f: frequency (Hz), t: time (s), x: distance (mm) from the origin point of the surface of the magnetic core, and τ is the pole pitch (mm). As shown in the figure, the pole pitch is half the wavelength of the magnetic flux; that is, a half cycle. As is clear from the above formula, B is a progressive magnetic field that moves to the base-right over time. (Figure 3(a) shows the relationship at the time t = 0). Figure 3(b) is a typical cross section corresponding to the line A-A in Figure 2. Accordingly, a magnetic field, having strong and weak [areas] is generated above cathode 12 parallel to the horizontal direction of magnetic core 20, just as if it were moving. In other words, as previously explained with Figure 8, a high-density plasma region is generated above cathode 12, and this plasma region continuously moves in one direction.

Moreover, the aforementioned magnetic field generation apparatus enclosure 14 is provided with a gas exhaust port 14a, and by means of gas exhaust port 14a the enclosure 14 is exhausted to a high vacuum of 10^{-4} (torr) or less to prevent discharge from the aforementioned magnetic field generation apparatus 40. Furthermore, an isolation valve 52 activated by means of an electromagnetic valve 51 is provided between enclosure 14 and the aforementioned etching chamber 13, and during etching these chambers 13 and 14 are separated by means of this isolation valve 52. In addition, in Figure 4 [sic; 1], 53 indicates an isolating material of [illegible] resin or the like, and 54 indicates an O-ring seal.

[Next], the operation of the present device, thus constructed, will be explained. First, a reactive gas of CF_4 or the like is introduced into etching chamber 12 [sic; 13] from gas inlet 13a and etching chamber 12 [sic; 13] is maintained at 10^{-4} (torr), after which high-frequency power (13.56 MHz) is applied to cathode 12, creating a glow discharge between cathode 12 and the anode (the upper wall of etching chamber 13) and generating a low-density plasma 61. Simultaneously, alternating current is run through the aforementioned coils 30 and due to the operation of intersecting magnetic fields E and B at each magnetic pole interval, as shown in the figure magnetron discharges of different phases, high, medium, and low, are generated; electrons undergo cycloid movement in the E x B direction while repeatedly colliding with the CF_4 molecules many times, so that a high-density plasma region 62 is generated across the magnetic pole intervals. As explained previously with Figure 3, this high-density plasma region 62 moves in one direction synchronously with the magnetic field, so the amount of deposition across the entire specimen 18 is fixed where the specimen is exposed to high-density plasma region 62. Therefore, the entire specimen is etched uniformly at a high speed.

Thus, with the present device, specimen 18 can be etched uniformly at a high speed due to the operation of magnetic field generation apparatus 40. Moreover, the size of magnetic field generation apparatus 40 can be only slightly larger than that of specimen 18, [so] the device does not have to be made larger. Furthermore, a mechanically moveable part becomes unnecessary, so the reliability is improved and, consequently, the structure of the device can be made smaller. /5 Moreover, with the present device specimen 18 is continuously exposed to high-density plasma 62, so even if the diameter of specimen 18 is increased the reduction in the etch rate is extremely small, and an etch rate (approximately 5 μm/min) that is close to the rate when the aforementioned magnetic pole intervals are at rest can be achieved.

Moreover, the device of the present application example has the following advantages when compared to the plasma processing device (Japanese Kokai Patent Application No. Sho 59 [1984]-17796) previously proposed by the present inventors; that is, as shown in Figure 11, because the former device uses a 3-phase alternating current 2-layer coil winding as magnetic field generation apparatus 40, the coil becomes a one-layer winding at either end of magnetic

field generation apparatus 40, so the ratio of the length [literally, 'dimension'] of the course of the moving magnetic field wherein a magnetic field with effective, uniform etching is obtained, is less than the overall length of the course of the moving magnetic field. Therefore, the course of the moving magnetic field of magnetic field generation apparatus 40 is longer than with respect to the size of specimen 18, and there is a risk that it will not be possible to secure the space [required] to enclose a moving magnetic field that would correspond to an increase in the diameter of the specimen. In this regard, with the present application example the method of winding the coils is fixed with respect to the course of the moving magnetic field, so there is no unnecessary parts, as with the former, and the size of the course of the moving magnetic field can be shorter than with the former. Consequently, a more compact magnetic field generation apparatus can be achieved and the problem related to the space [required] to enclose the moving magnetic field can be solved.

Figure 4 is an explanatory diagram of the structure of the essential components of a second application example of the present invention. This application example differs from the previously explained application example in that Helmholtz coils 71 and 72 are provided above the aforementioned cathode 12; other than that it is identical to the previous application example.

With this type of structure, when current runs through Helmholtz coils 71 and 72 the strength of the magnetic field over the surface of specimen 18 can be increased; therefore, there is an advantage in that the horizontal magnetic field at the surface of the specimen is larger, and the acceleration voltage of the ions is greatly reduced, so that radiation damage is significantly reduced (cf. Y. Horiike, H. Okano; Jpn. J. Appl phys. 20 (1981) L 817).

Figure 5 is a diagram illustrating the overall structure of a dry etching device pertaining to a third application example of the present invention. Note that portions that are identical to those in Figure 1 are given the same codes, and a detailed explanation thereof is omitted. This application example differs from the first application example in that the aforementioned magnetic field generation apparatus 40 is situated in atmospheric conditions. In other words, with a device having the aforementioned magnetic field generation apparatus 40, even when the size of the magnetic field generated by the magnetic pole intervals and the amount of the high-frequency power are sufficiently reduced, an etch rate that exceed that of the conventional device can be obtained. Therefore, cathode 12 can be made sufficiently thick (10 mm or more), and even when a magnetic field generation apparatus enclosure 14 that is under a high vacuum is not provided, there is almost no risk that magnetic field generation apparatus 40 will discharge or the like.

Accordingly, with the present application example the same effect as with the previous application examples can of course be obtained, and there are advantages such as that the structure of the device can be simplified.

Figure 6 is a diagram illustrating the overall structure of a dry etching device pertaining to a fourth application example of the present invention. Note that portions that are identical to those in Figure 1 are given the same reference numbers, and a detailed explanation thereof is omitted. This application example differs from the first application example in that a magnetic material is embedded outside of the perimeter of the aforementioned cathode 12. In other words, a metal plate 80 is embedded in the area outside of the region where the aforementioned specimen 18 is arranged on the upper surface of cathode 12.

With this type of structure, even if the end portions of the aforementioned magnetic pole intervals are assumed to be under metal plate 80, the major portion of the magnetic field lines are transmitted within metal plate 80, which has a high permeability, [so] a magnetic field is not generated over metal plate 80. Therefore, the high-density plasma region 62 at the perimeter of specimen 18 is eliminated. Accordingly, the uniformity of the course of the progressive magnetic field can be improved and an etch rate with an even greater uniformity can be achieved.

Note that the present invention is not limited to the aforementioned application examples. For example, the coils of the aforementioned magnetic field generation apparatus are not limited to a 3-phase winding, as long as they are more than 2 phases – preferably, a 3n phase (where n is a positive integer). In other words, as long as the magnetic field generation apparatus is comprised of a magnetic core and multiple magnetic coils and can generate a magnetic field above the aforementioned cathode, and this magnetic field can be moved continuously in one direction, it is permissible. Moreover, the size of the groove formed in the magnetic core, as /6
well as the intervals, can be changed appropriately according to the specifications. Furthermore, the current run through the coils is not limited to a 3-phase alternating current; a current corresponding to the number of phases of the coils – that is, a current of more than 2 phases is permissible. Here, the more the number of phases of the alternating current and of the coils is increased the more uniform is the obtained distribution of the magnetic field. Moreover, multiple specimens can be etched by forming the aforementioned cathode in a track shape, as shown in Figure 7, and by forming the magnetic field generation apparatus as well in a track shape; in this way an improvement in mass production ability can be obtained. Furthermore, if a means to prevent the specimen from falling is added, the relationship of the upper and lower [components] of each of the application examples can be reversed. Moreover, the specimen is not limited to SiO_2; it can of course be a substance that is appropriate to whatever film is to be etched.

Moreover, the device of the present invention is not limited to etching; it can be applied to film formation [by] plasma CVD, sputtering, or the like, or an ashing process. However, in the case of sputter deposition it is necessary to arrange a target as the specimen on the aforementioned cathode and to arrange a material on which a film is formed on the aforementioned cathode. In this case, just as with the previously explained etching of the

specimen to be etched, the target is etched uniformly at a high speed, so the film can be formed on the specimen at a high speed, and the film can be formed with a uniform thickness. Moreover, just as with etching, the magnetic field can be moved in one direction while the magnetic field generation apparatus is stationary, so the structure of the device can be more compact and a mechanical moving part is unnecessary, improving reliability. Furthermore, the gas to be excited that is introduced into the etching chamber can be selected appropriately according to the target or according to the specimen to be etched that is on the cathode. In addition, other variations in the application can be made without departing from the scope of the present invention.

Brief description of the figures

Figures 1-3 are for the purpose of explaining a dry etching device pertaining to the first application example of the present invention: Figure 1 is a diagram illustrating the overall structure, Figure 2 is an oblique view of the structure of the magnetic core, and Figure 3 is a typical diagram illustrating the winding of the coils and the generated magnetic field. Figure 4 is an explanatory diagram of the structure of the essential components of a second application example. Figure 5 is a diagram illustrating the overall structure of a third application example. Figure 6 is a diagram illustrating the overall structure of a fourth application example. Figure 7 is an explanatory diagram of the essential components of an alternative example. Figures 8 through 10 are for the purpose of explaining the problems with the prior art: Figure 8 is an oblique view illustrating the principle of a dry etching device that uses magnetron discharge, Figure 9 is a characteristic graph showing the relationship between the location of the specimen and the etching depth, and Figure 10 is a typical diagram illustrating the relationship between the magnetic pole intervals and the location of the specimen. Figure 11 is a diagram illustrating the overall structure of a plasma processing device (Japanese Kokai Patent Application No. Sho 59 [1984]-17796) previously proposed by the present inventors.

Explanation of the reference numerals

11	Etching container
12	Cathode
13	Etching chamber (plasma processing chamber)
13a	Gas inlet
13b, 14a	Gas exhaust port
14	Magnetic field generation apparatus enclosure
15	Matching circuit
16	High-frequency power source
17	Cooling water conduit

18	Specimen to be etched
20	Magnetic core
20a	Roughly tooth shape core
20b	Back core
21	Groove
30, 31a, 31b, 31c	Coils
51	Electromagnetic valve
52	Isolation valve
61	Low-density plasma region
62	High-density plasma region
71, 72	Helmholtz coils
80	Metal plate

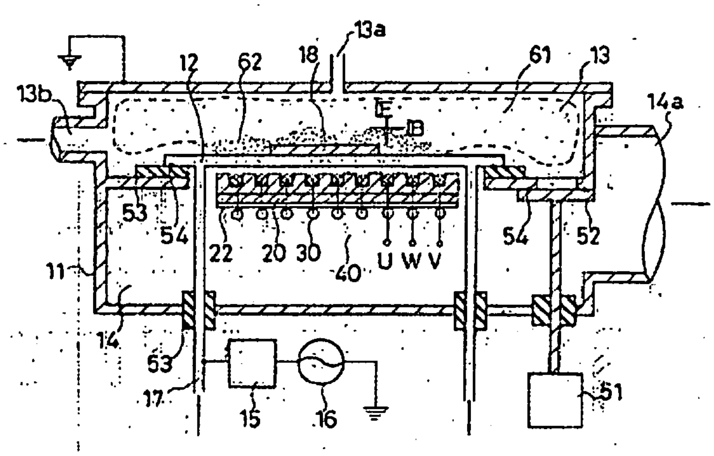

Figure 1

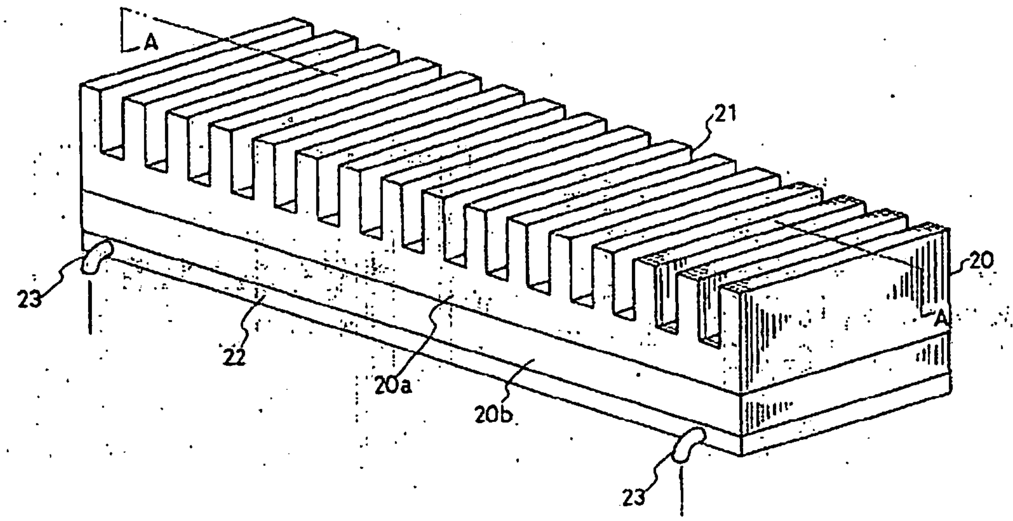

Figure 2

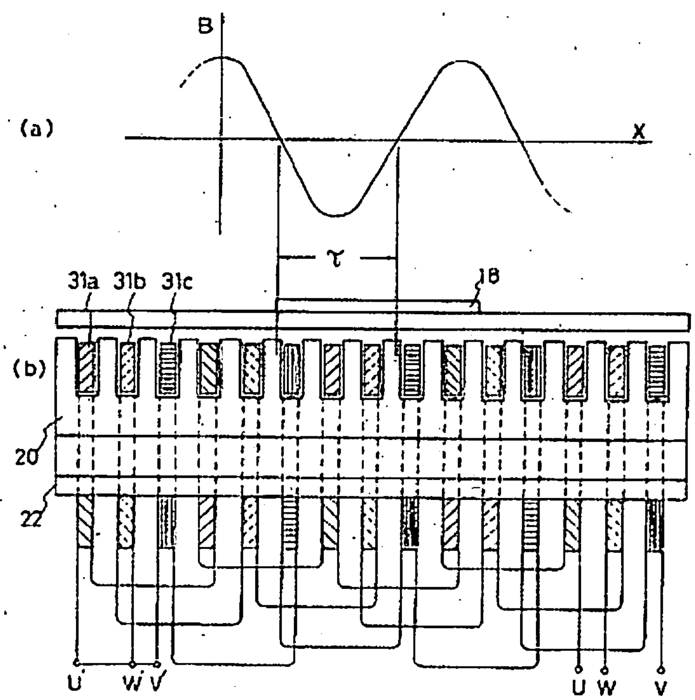

Figure 3

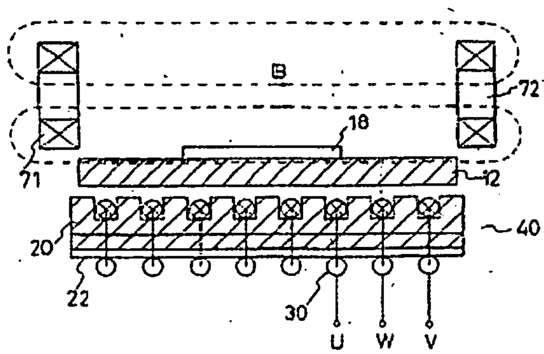

Figure 4

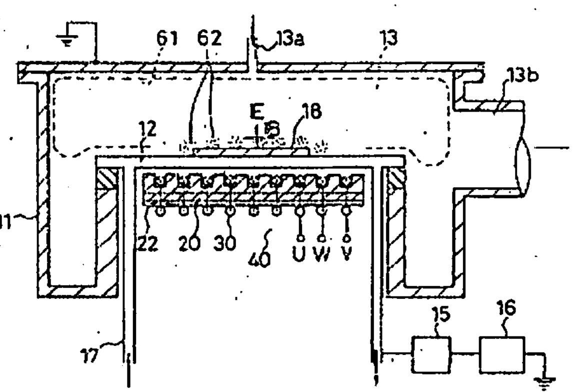

Figure 5

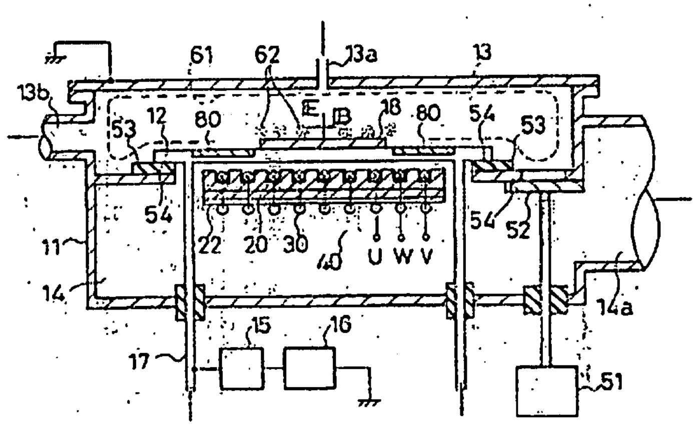

Figure 6

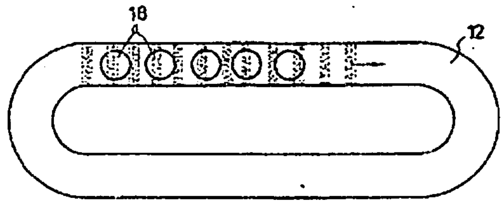

Figure 7

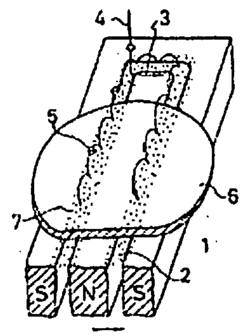

Figure 8

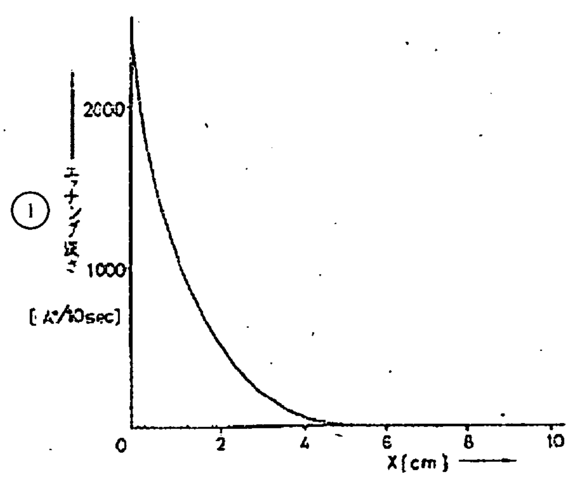

Figure 9

Key: 1 Etching depth

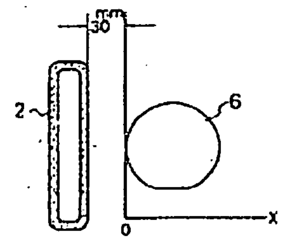

Figure 10

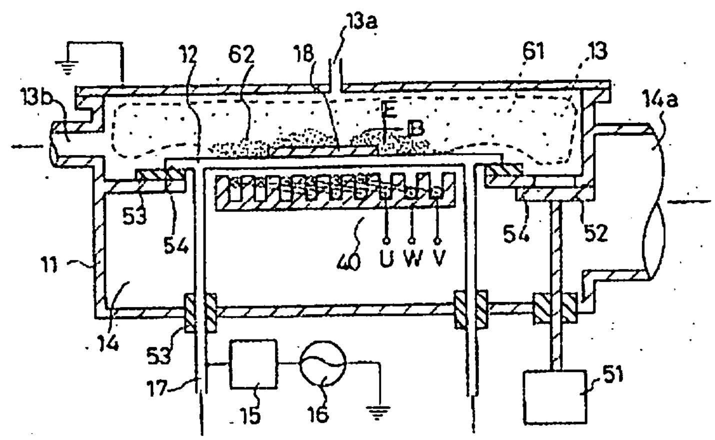

Figure 11